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MEASURING INFORMATION CONTENT IN LONG-RANGE FORECASTS

by

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and
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FOREWORD

This memorandum was presented at the Military Policy Evaluation: Quantitative Applications workshop conference hosted by the Strategic Studies Institute in mid-1977. During the workshop, sponsored by DePaul University and the Strategic Studies Institute, academic and government experts presented the latest findings of formal models and statistical-mathematical approaches to the processes of military decisionmaking, assistance, intervention, and conflict resolution.

The Military Issues Research Memoranda program of the Strategic Studies Institute, US Army War College, provides a forum for the timely dissemination of analytical papers such as those presented at the workshop.

This memorandum is being published as a contribution to the field of national security research and study. The data and opinions presented are those of the author and in no way imply the indorsement of the College, the Department of the Army or the Department of Defense.

ROBERT G. YERKS
Major General, USA
Commandant

BIOGRAPHICAL SKETCHES OF THE AUTHORS

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MEASURING INFORMATION CONTENT IN LONG-RANGE FORECASTS

In the past 5 years there has been a dramatic shift in the requirements for technological forecasts of enemy weapons systems. For example, many forecasts now require the estimation of annual traces of upper and lower boundaries within which the real values should fall a specified percentage of the time. Thus were an analyst forecasting the number of foxbats for the next 10 years, he might be asked to present for each of the next 10 years, an upper and lower estimate such that there would be a 75 percent chance that the real value would fall within the range. In addition, analysts are often asked to present their best or most probable estimates. Furthermore, for any given weapon, there may be a complete set of such forecasts including for example not only the number of weapons forecast into the future, but also a number of the performance characteristics of the weapon. Indeed, in some instances, even textual descriptions such as anticipated mission are now being systematized by requiring that a probability be associated with each alternative.

While the requirements for these types of forecasts differ somewhat by agencies, the short-term trends are apparent and in some cases already reality. That is, wherever possible, analysts are being asked or

required to express their estimates numerically with probability estimates and best estimates.

One of the associated difficulties (aside from the difficulty of actually performing the task) is that the array of numbers cannot easily be summarized by the planners who are the recipients of the forecasts. The first decision concerning any forecast which a planner must make is whether it is anything against which he or she should bother to develop plans. While there are many criteria which the planner should use to make such a judgment, one of the primary factors should be the amount of information which is contained in the estimate. Presumably, a forecast which contains very little information should be taken less seriously than would one which is quite informative. Of course, if a weapon which looks potentially quite menacing has very little information describing it, a very reasonable action would be to improve the information content. Then if it continues to appear as menacing, plans should be seriously considered to account for this addition to the enemy's arsenal. However, at present, such decisions are complicated by the fact that there is no mechanism to develop an aggregate measure of the quantity of information contained in a given set of forecasts of the various aspects of a given weapon or weapon system.

This paper will present a methodology for measuring the information content of the total set of forecasts across all categories for any given weapon.

In general, these types of forecasts are concentrated attempts to provide planners with the best information available as to the size, characteristics, and distribution of enemy weapon systems in the medium-term future. They provide a means of defining the threat that exists in future timeframes. Let us assume that an estimate is composed of three components: a range of forecasts of (1) the future order of battle, (2) the characteristics and performance of the system, and (3) textual information pertinent to estimating deployment and usage.

The analysts' information is never constant. Instead, it varies as new intelligence is made available to them. Information such as a shift in emphasis from interceptor aircraft to missile defense would change an analyst's estimate of the number of each system likely to be present in the future. This information varies in the degree of confidence an analyst attributes to it. New weapon systems, especially those in developmental or prototype stages, present particularly difficult problems. The shift from a paper system to a prototype test system and then to a deployable system all represent shift stages in the confidence an analyst feels about the estimate.

Of obvious importance to planners is the amount of information there appears to be in a given estimate. More information would allow them to better perform their tasks of prescribing force structures and contingency plans to counter the threat. The more information, the more definitive they can plan the shift in forces needed. Providing a measure of such a signal is a surprisingly easy task. The method derives from a well-developed body of knowledge called information theory.[1] Although it may seem somewhat surprising that we can measure information, we will attempt to show that it not only can be done, but can handle some extremely complicated side issues.

When reduced to the basics, information theory is the log of the ratio of two probabilities: the probability assigned by analysts that some phenomena will occur given their specific knowledge of the situation and the probability which would have been assigned assuming that the estimate was made at random. The former is usually information specific to a given case. Thus, if you are trying to estimate the number of foxbats in the next 10 years, you might have received Soviet planning documents which laid out some information specific to foxbats. The latter probability can be thought of as actuarial type information. Let us say, for example, that you had data on the overall trends of Soviet interceptor aircraft but no detailed information on any specific interceptor. Your "random" estimate then would be the same for each of the types of Soviet interceptors and they would reflect the known overall distribution of that class. To bring the example a bit closer to home, assume that you were trying to estimate the height of an unspecified human person living in 1977. Your random estimate would simply be the average height of all humans taken from whatever actuarial tables compute such numbers. The classes can, however, be changed. You could, for example, be asked to estimate the height of an unspecified adult American female. Your "random" estimate would be different, but only because you would have to look on a different portion of your table. The "specific" estimate in the numerative would have to be based on additional information specifically pertinent to the individual whose height is being forecast.

In the basic, discrete case, the relationship between probabilities and information is stated by the following equation:

$$I = \log \left(\frac{p\,(y)}{p\,(x)}\right) \qquad (1)$$

where I is the information present in an estimate, p(y) is the probability assigned to an event after some communication (y) has been

transmitted, received, or accumulated. $p(x)$ is the probability assigned to an event (x) if we had chosen at random. The value $p(x)$ is the minimum probability of event (x) because we can always do as well as chance. Stated differently, pure chance is the minimum information available to an analyst.

We find that it is convenient to state equation (1) a little differently. Because we are dealing with the log of the ratio of the probabilities, we can subtract the logs to get the following equivalent statement.

$$I = \log(p(y)) - \log(p(x)) \qquad (2)$$

Dealing directly with logs of probabilities normally is confusing because they are always negative numbers. Therefore, information theorists have invented the concept of "uncertainty" which they call H. Uncertainty is equal to the negative of the log of the probability. Thus uncertainty is a positive number which gets larger as probabilities get smaller. In equation (2), $H_y = -\log(p(y))$ and $H_x = -\log(p(y))$. *H_x is called the maximum uncertainty* because it is the uncertainty associated with choosing at random. *H_y is the absolute uncertainty* because it is the uncertainty associated with the content of the message at hand.

The information in the message then is equal to

$$I = H_x - H_y \qquad (3)$$

This is the basic working equation of information theory. The information in a message is the difference between the uncertainty of randomness and the uncertainty after the message has been received. In some instances, the mathematics associated with the evaluation of equation (3) can become very tedious, but they can always be brought back to that basic question.

The use of equations (1)-(3) can be demonstrated in the following example. Assume that I have chosen a number between 1 and 10 and ask you to guess what it is knowing only that each number is equally probable. Under these conditions, you have no better than a 1 in 10 chance at guessing the number correctly. Thus, your information is equal to:

$$I = \log \frac{p(y)}{p(x)} = \log \frac{\text{(probability after the message)}}{\text{minimum probability}}$$

$$= \log \frac{.10}{.10} = \log 1 = 0 \text{ or } I = H_x - H_y = 3...-3...=0.$$

Assume, however, that a friend whispers in your ear that I do not choose my numbers randomly. Rather, he tells you, I have a strong preference for the number 6 and that I can be counted on to choose it about 40 percent of the time.

Now your information is:

$$I = \frac{\text{probability after the message}}{\text{minimum probability}} = \log \frac{.40}{.10} = \log 4 = 2$$

or $I = H_x - H_y = 3 \ldots -1 \ldots = 2$. (Assuming we are using log base 2.)

In most of our cases we will not be dealing with discrete systems like the digits between 1 and 10 but with continuous functions such as speeds and weights of airplanes. This means that rather than dealing with specific probabilities, the equations must be expressed as continuous probability functions. This is not difficult to do, but we will not present the math here. It is sufficient to recognize the difference.[2]

DEVELOPING THE MEASURES OF INFORMATION

If we wanted to actually estimate the uncertainty in the forecasts of weapons systems on a practical basis, we would need the following five measures.

- maximum uncertainty (basic)
- maximum uncertainty (modified)
- weightings
- absolute uncertainty
- corrections for quality of input data

For the purposes of clarification, let us first, however, define a small vocabulary to help improve the chances of communicating what the research orientation looks like.

- weapons category—a broad category of weapons which are normally classed together such as fighter aircraft or long-range bombers.
- weapon—a specific weapon within a weapons category, such as a foxbat.
- weapons component—some part or characteristic of a weapon such as speed, or weight.
- major document category—one of the three major sections of the forecasting document (i.e., future order of battle, characteristics and performance, textual discussion).
- document subcategory—one of the specific estimates within the C&P or textual sections of the document (e.g., speed or mission).

Having provided a few basic definitions we can proceed to the methodology.

MAXIMUM UNCERTAINTY (BASIC)

General. As we have said before, the basic foundation of information

theory is that the information content of any message is equal to the reduction in the uncertainty from what we would have known had we simply chosen at random. The complexity of that statement is unveiled when we begin to ask ourselves what it means to choose at random. What, for example, is the distribution of estimates of speed which we would obtain by randomly guessing the speed or altitude of a foxbat. Clearly the "at random" aspect of any estimate is bounded by a range of previous estimates of both the foxbat *and* other planes similarly configured.

Information theorists have come to some unanimity that randomness is a matter of perspective of the viewer. That is, "randomness" can vary considerably depending on the choice of the classification system used by the analyst. However, once we are able to agree on a classification system, the definition of randomness becomes as rigid as it was previously ephemeral. In our case, the classification system is obvious—the weapons categories of the forecast document. A foxbat, for example, is a member of the class of Soviet interceptor aircraft. Thus, were we estimating the speed of foxbats at random, it would be assumed that we would know the distribution of speeds of Soviet interceptor aircraft. If we are attempting to measure the information content in a knowledgeable estimate of the speed of a foxbat, we simply have to measure the improvement of our knowledge-based estimate over our estimate had we known *only* that it was a Soviet interceptor aircraft. Our general problem in measuring maximum uncertainty then is to identify the probability distributions of all of the document categories and subcategories for each of the weapons categories under consideration.

Future Order of Battle. Since we are forecasting the number of weapons of a particular type 10-20 years in the future, we need to know the diversity of the larger system across the last 20 years. Thus, for the case of fighter aircraft, we would want to know, since 1957, how many of each type of fighter aircraft the Soviets have had. From this we can calculate a measure of dispersion of the weapons system across the most recent 20 years.[3] It is this dispersion which provides the historical or "random" knowledge base for calculating the ratio of current knowledge to historical knowledge.

Characteristics and Performance. The operations here are identical to those described above except that they must be done for each subcategory within the C&P section. Thus, for fighter aircraft, we would have maximum uncertainty for speed, range, etc. for all of the subcategories which we anticipate using.

Textual. Since the categories in the textual section are likely to be discrete rather than continuous, the calculation of maximum uncertainty is likely to be simpler. For example, it is highly likely that we will be able to use random sampling methods to determine, for example, the probability that a fighter aircraft will be primarily used for close air support rather than dogfighting. Alternately, for those questions addressed in the textual section, it may be possible to use the judgments of current experts on the weapons category under consideration.

MAXIMUM UNCERTAINTY (MODIFIED)

General. Although it may seem somewhat counterintuitive, the maximum uncertainty of a weapons category is not constant. Aside from the fact that it can change across time,[4] it can change as a function of the relationship between the variables whose values are being estimated. Consider the following example. Let us say that your task is to estimate the height, weight and sex of a person about whom your intelligence sources have gathered some information. Yet before looking at your information, you decide to calculate your basic measures of uncertainty. Being a reasonable person, you take out your actuarial tables which tell you that the probability that this person will be male is .48, and that the means and standard deviations for height and weight are m_h, s_h; m_w, s_w respectively. From this data you proceed to calculate the uncertainties H_m, H_h and H_w respectively.

Having done this, you open your packet of data and we find that your data sources tell you that the person is definitely a male and that there is a 75 percent chance that he stands between 6'6" and 6'8" tall. You ask where the data on weight is and are told that it was determined that you did not have a need to know. "Very well," you mutter to yourself and decide that knowing that this person is probably 6'6" to 6'8" and male significantly narrows down the possible range of weight so you look at your tables and conclude that there is a 75 percent chance that he weighs between 230 and 250 lbs.

The question is, "How much information have you provided your planner on weight?" The answer is "none." You get credit for the reduction on uncertainty on height and sex, but given that you knew their values, you did no better than choose the weight at random. What changed was the base from which your randomness was computed. By the time you got around to estimating weight, you had a very easy

problem to solve and you added no information to what the planner could have figured out for himself.

This adjustment is rather easy to make in theory although it can get a bit messy in practice. Theoretically, all that needs to be done is establish the relationship between the variables and readjust the maximum uncertainty given the knowledge of the other variables. In the example, you would simply have identified the probabilities that a person would have "x" weight given your knowledge of height and sex. Once you have that contribution, you may either integrate it or assume normality and calculate its standard deviation.

In our case, the problem is only slightly more tedious. For example, maximum speed and weight might estimate the number of fighter aircraft deployed. Similarly, wing span, weight, and wing angle might estimate take-off speed. These could be translated into linear equations and fit against the same historical data used to compute the basic maximum uncertainty. Each of the equations will have a measurable fit with the data called R^2. The value of R^2 is equal to the amount of variation which can be accounted for by the equation. From this we can compute an *estimated* uncertainty. If the estimated uncertainty is less than the basic uncertainty, we should reduce the basic uncertainty by an amount proportional to the R^2. Basically, this process permits us to measure one of the sources of double counting of the same information and to adjust for it by altering the value of the maximum uncertainty. Stated differently, this adjustment prohibits the analyst from getting credit for solving particularly easy problems.

Future Order of Battle, C&P, Textual. It is really impossible to discuss these categories independently because the essence of modified uncertainty is that it is necessary to correct for the effects of interrelationships between categories and subcategories. The most difficult practical task will be the delineation of the initial set of equations to be tested. Included in the decision to test certain equations and not others would be an understanding of the normal sequence undertaken by the analyst. If, for example, he nearly always writes the textual section last, one might develop equations predicting mission from the estimated OB and certain aspects of C&P. If the sequence were reversed, the structure of the equations would be accordingly altered. If both sequences are likely, the computer would have to scan the uncertainties to determine the most probable sequence for that case. This could be done using the theory of causal inference.

WEIGHTINGS

General. The categories within a given forecast are not equally important. Future order of battle, for example, may be more or less important than any given performance characteristic, but it is unlikely to be equal in importance. Because of this, the categories must be weighted. The weighting of the major categories and the subcategories would be one of the more important factors in measuring the information content. Ultimately, the weighting has to reflect the thinking of the planners who will use both the document and the information measure. There is much that could be done to attempt to make the weightings as sound as possible. One option would require a set of short open-ended discussions with users of the forecast, writers of the forecast, users and developers of wargames and simulations, and others who could be expected to be knowledgeable about the subject being forecast. From them one might hope to gather three types of information: (1) the weights which they would attach to the document categories; (2) the criteria they used to identify these weights; and (3) any contingencies which they felt appropriate. Some of the interviewees might, for example, believe that the dollar impact on the US planners must be the primary weighting criterion while others might believe that the impact on Soviet fighting capability should be most important. One might also find that some of the experts would posit a number of contingencies such as the argument that the estimated type of mission could well influence the weightings for different weapons within a total weapons category, while others might argue that variations at the high and low ends of the range of uncertainty are not as important as are those variations around the middle ranges (i.e., the weightings are not linear).

From these suggestions, the most dominant patterns of weighting systems should be programed and the results examined for face validity. Ultimately, of course, the decisions of the weighting schemes will be determined by the subjective judgments of the forecasters and planners who develop and use the forecasts.

ABSOLUTE UNCERTAINTY

General. Absolute uncertainty is that measure of the uncertainty of the specific estimate being considered. Of all of our measures, it is certainly the easiest to compute or develop. If it is to be computed, the

range of the values estimated by the forecaster, taken in conjunction with the relative location of the "best" estimate can be combined with the assumption of a skewed Gaussian distribution to permit the calculation of the absolute uncertainty for the future OB section and for each of the subcategories of the C&P section. For the discrete case in the textual section, the logs of the probabilities provided by the analyst are all that are needed.

Alternatively, absolute uncertainties can be subjectively estimated by the analysts. They simply have to provide a number for each of the major categories (within the limits set by the weightings, of course).

Future Order of Battle. Whether developed subjectively or numerically, there is but one number defining the absolute uncertainty of the future order of battle. Subjectively, it would be a number assigned by the analysts having been told what the weightings are and having been provided with a calibration instrument so that they know what scores should be attached to varying levels of information content.

Numerically the absolute uncertainty is approximately equal to the standard deviation of the range of estimates for a given weapon. Specifically, it is the integral of the log of the probability function times the probability function. That is,

$$H_y = \int p(y)\log(p(y))dy^5$$

Where H_y is the absolute uncertainty

$p(y)$ is the probability density function implied by range of the estimates.

Characteristics and Performance. The calculation of absolute uncertainty for this section is done somewhat differently depending on whether it is done arithmetically or subjectively. When it is done subjectively, a single estimate for the entire category is supplied by the analyst. For this instance particularly, the subjective estimate should be capable of capturing some of the uniqueness involved in estimating various elements of this particular weapon in this particular time period.

When numerical methods are used, the range of estimates and the best estimates (if they are provided) would be used as in the future OB case to provide the definition of the probability density functions. However, in the C&P case, these functions would be developed (by the computer) for each of the subcategories. It is then a trivial task to compute the integrals to provide the estimate of the absolute uncertainty for each of the subcategories. These would then be

combined into a total for the category using the method to be described below in the section "Putting It All Together."

Textual. The absolute uncertainty for the textual section would be very easy. Subjectively it would be computed just like the C&P section. Numerically, information theory permits the direct processing of the probability of discrete events. There is no need for an intermediary step of computing a probability density function. The uncertainty of any subcategory (say mission) is simply the log of the probability as assigned by the analyst. As in the case of the C&P section, the subcategories can be combined as we will show later in this proposal.

CORRECTIONS FOR THE QUALITY OF INPUT DATA

General. One of the problems in developing forecasts such as we are considering is that there is no rigorous method of controlling for the variations in the quality of the historical data upon which the forecasts are based. In some instances, forecasts are based on a solid well-documented historical tracking of performance and deployment. In other cases, those data are of inconsistent quantity and quality. For new systems, there may be no more than sketchy documentation of limited aspects of some weapons which exists only on Soviet drafting boards.

Because it is difficult to include the data errors in the forecast, one option which is occasionally used is to make the forecasts as though the data were perfect and then to provide an additional estimate of the data accuracy. Subsequently, the planner uses subjective judgment to evaluate the forecast. This approach has been less than satisfactory.

An alternative is to compute the information measure including data error. We know from classical statistics that because of randomizing effects, errors in summary measures (such as these forecasts) decrease predictably as the simple quantity of data increases. Specifically, it decreased proportionately with the square of the number of data points minus one.

This fact enables us to adjust for the value of the probability function in the computation of the absolute uncertainty. It is easy to show that we need only add the term log $(p(1\text{-}e))$ to equation (3). The term "e" refers to the estimated error in the forecast due to the data error.

So far we have assumed that the error in the data and the range of estimates are unrelated. In fact this is unlikely to be true. Despite

instructions to the contrary, analysts realizing the weakness of their data probably hedge their estimates more than they might have done had they thought the data were better. To correct for this, we can measure historically the strength of the relationship between the quality of the data and the range of estimates. The strength of that relationship is the R^2 of a regression equation and tells us the amount of overlap we can normally expect between the two variables. Thus we would want to subtract the overlap from the estimate of information. This can be done very simply.

$$I = \log(p(1\text{-}e)) - R^2 \,.\, \log(p(1\text{-}e)) + H_x - H_y \qquad (4)$$
$$= (1\text{-}R^2) \,.\, \log(p(1\text{-}e)) + H_x - H_y$$

While the adjustment of the information content for *varying* levels of quality of input data is not a trivial exercise, perhaps its most important role for this correction mechanism comes in the ability to alter the information content for systems which have yet to be put into production.

Although we do have information on these weapons, our problem is that we do not know at present how to evaluate it relative to standard time series of conventional historical data. To address this question, it would be necessary to establish subjectively some rules of thumb about the quality equivalence of the type of intelligence data for a developing weapon and "hard" historical facts about existing and operating weapons through discussions with analysts and others knowledgeable about the subject being forecast. These rules of thumb could, for example, be a function of the number of years that a particular weapon has been in developmental stages. Thus the first year that some new weapon is reported, the information content may be severely downgraded. In subsequent years the adjustment may move slightly upwards. Thus, as a weapon moves from planning through development to deployment the error estimates will slowly decrease. After the initial deployments, the more rigorous methods at accounting for error would be employed.

PUTTING IT ALL TOGETHER

We have presented a number of concepts feeding into information theory in one manner or another. Now, we will attempt to tie them all together into a fairly short coherent package. We start with the assumption that we have three sections for which there are forecasts: future order of battle, characteristics and performance, and textual

description. The latter two contain several identifiable subsections for which there are forecasts associated with probabilities and/or ranges and best estimates. Future order of battle forecasts only one phenomena which provides us with a range and a best estimate.

We have suggested a method which would compute information content measures for each of these elements, weigh them, make corrections for interrelationships between the variables and correct for faulty input data and add them together. The final information measure could range from zero to 100 where zero is no information and 100 is certainty. Let us quickly review the method for accomplishing this task. We know that for any single estimate, the information is the log of the ratio of the probability of the estimate to the probability had we chosen at random

$$I = \log \frac{p(y)}{p(x)}$$

In this equation p(y) is roughly equivalent to the range of any given forecast. The p(x) is roughly equivalent to the range if the analyst had known nothing about the weapons except the category within which it fits. It is convenient to define variables H_y and H_x which are equal to minus the logs of the numerator and denominator respectively. They are formally called the *absolute uncertainty* and the *maximum uncertainty*. Therefore, the information for a given estimate such as speed or mission is simply the difference between them.

$$I = H_x - H_y$$

We found, however, that the maximum uncertainty is not a constant. It is a function, in part, of the relationships between the forecast under immediate investigation (say speed of a foxbat) and the other variables in the estimates (say weight and armament). Therefore the value of H_x has to be changed by a two-step process which leaves us with the following slight modification:

$$I = \hat{\hat{H}}_x - H_y$$

where $\hat{\hat{H}}_x$ implies that we are dealing with the second estimate of H_x.

Even the single estimate is still not complete for we have not yet corrected for the variations in the quality of the input data. This is a straightforward calculation which results in the addition of a small negative number to the information content. That revision creates the following modification:

$$I = (1-R^2)\log(p(1-e)) + \hat{\hat{H}}_x - H_y \qquad (4)$$

Where R^2 is a measure of the amount of data error the analyst has already included in his estimate and e is the measure of how much error

the data inaccuracies will introduce into the forecasts. This correction is particularly important because it is the mechanism by which the information measures of weapons systems under development will be adjusted downward.

To this point, we have presented a mechanism by which the information content of any specific estimate can be measured. The measures are all generated on identical scales and are therefore additive. We have not yet accounted for the fact that the various parts of the total estimate are of obviously different importance. Estimates of the mission of a fighter aircraft are not exactly as important as the estimates of its speed or of the number of aircraft which are expected to be placed in service 20 years from now.

To account for this problem, it would be necessary to develop a weighting system for each of the specific estimates. This would almost certainly be a two-stage process for which future order of battle estimates might hypothetically be given a maximum of 50 points, characteristics and performance 30 points and the textual section 20 points. Within the latter two sections, the subcategories could be assigned points assuring that the total could not exceed the maximum for the overall category.

These weightings would then be multiplied to the entire information measure for any given estimate. Thus if there were a weight W_1 for some specific estimate (e.g., future order of battle) the information for future OB would be

$$I_1 = W_1 \left[(1-R_1^2) \log (p(1-e_1) + H_{x_1} - H_{y_1}\right]$$

Although this equation applies to the estimate of only one specific component of a specific type of weapon, information theory has the advantage that the units of "I" are always comparable assuming the proper factors have been taken into consideration. Thus, if we had a very simple weapon (e.g., some type of fighter aircraft) with two components of C&P (e.g., weight and speed) and two components of text (e.g., mission and location), we would have a measure of the information for each of these four elements and for the estimate of the future order of battle. Therefore we could array the information as shown below:

$$I_{\text{future OB}} = W_1 \dot{I}_{\text{future OB}}$$

$$I_{\text{C\&P}} = W_{2_1} \dot{I}_{\text{speed}} + W_{2_2} \dot{I}_{\text{Weight}}$$

$$I_{text} = W_{3_1} \hat{I}_{mission} + W_{3_2} \hat{I}_{location}$$

$$I_{total} = I_{future\ OB} + I_{C\&P} + I_{text}$$

The system envisioned in this paper could operate in such a manner that an analyst could employ a computer work space advantageously in his task. The computer software for such a system could operate with virtually no human intervention if the analyst or planner wanted. The analyst would be storing his estimates and a subjective estimate of absolute uncertainty which he can update at any time. We believe that he should be using a computer work space, updating it with new information which can go final at any point in time since it contains up-to-date information. There should be, also, the opportunity for supervisors to intervene and override the system defaults in a number of points. For example, the supervisor should have the option of suppressing the computation of the selected interrelationships between subcategories in the event that, for one reason or another, they do not apply to the weapons subsystem under consideration. If, for example, certain VTOLs were listed in the category of fighter aircraft, many of the interrelationships based on fixed wing aircraft would be totally irrelevant.

Finally, when operating under default, the system would compute the absolute uncertainty based on the spread, best estimates, and the appropriate skewed Gaussian probability distribution. We suggest that a better system would provide the user with the option of selecting among a small number of alternate distributions. While we expect that this option would be rarely used, it could be an important exercise in the event that there were serious disagreements about some particular estimate and the associated information content.

ENDNOTES

1. See Shannon and Weaver (1949), Goldman (1968), Thiel (1967), and Garner (1962) for examples of similar applications and development of the theory.
2. See Goldman (1968) and Watanabe (1969) for developments.
3. The actual number of years (20) in this example is not intended to be the number needed in real estimates. It may vary from weapon system to system.
4. Because average speeds, weight, numbers deployed, etc., change across time, the averages from which maximum uncertainty are computed will be expected to change.
5. For Gaussian's distribution, this is the standard deviation.

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This memorandum presents a methodology for measuringthe information content of the total set of forecasts across all categories for any given weapon.

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